Haptics/graphics-facilitated learning and neural recovery

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MARS-RERC
Machines Assisting Recovery from Stroke
Rehabilitation Engineering Research Center

Robotics
AT THE REHABILITATION INSTITUTE OF CHICAGO

Sensory Motor Performance Program (SMPP) at RIC

Northwestern University

Electronic Visualization Lab at UIC

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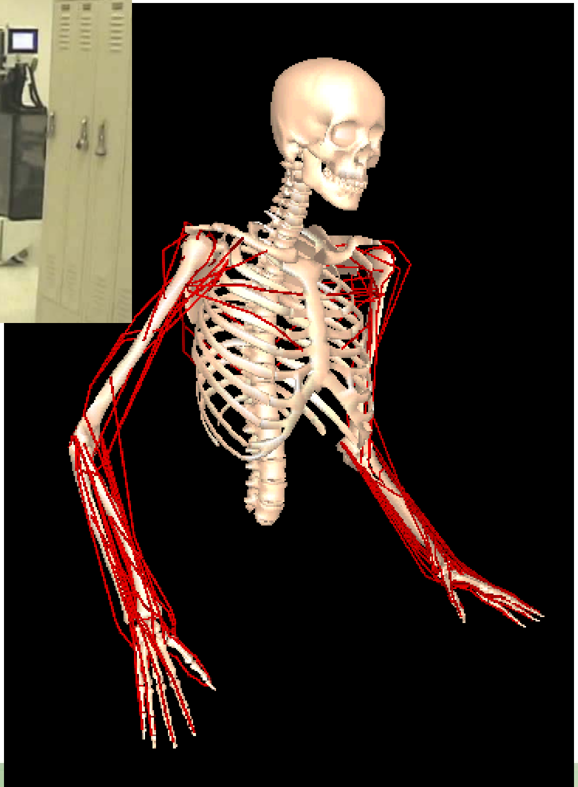
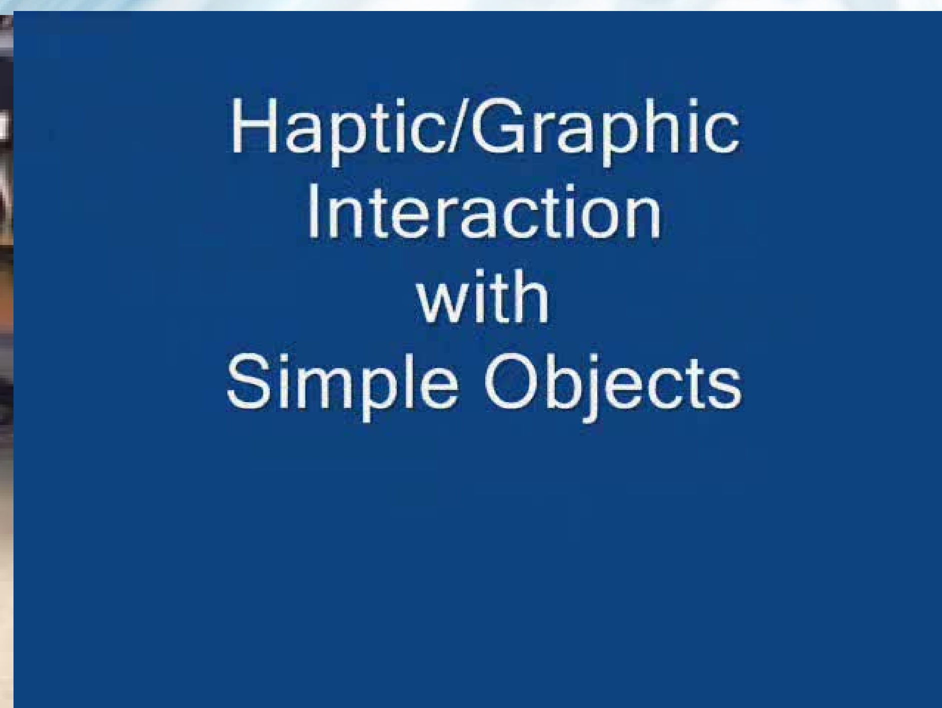
Research at the RIC



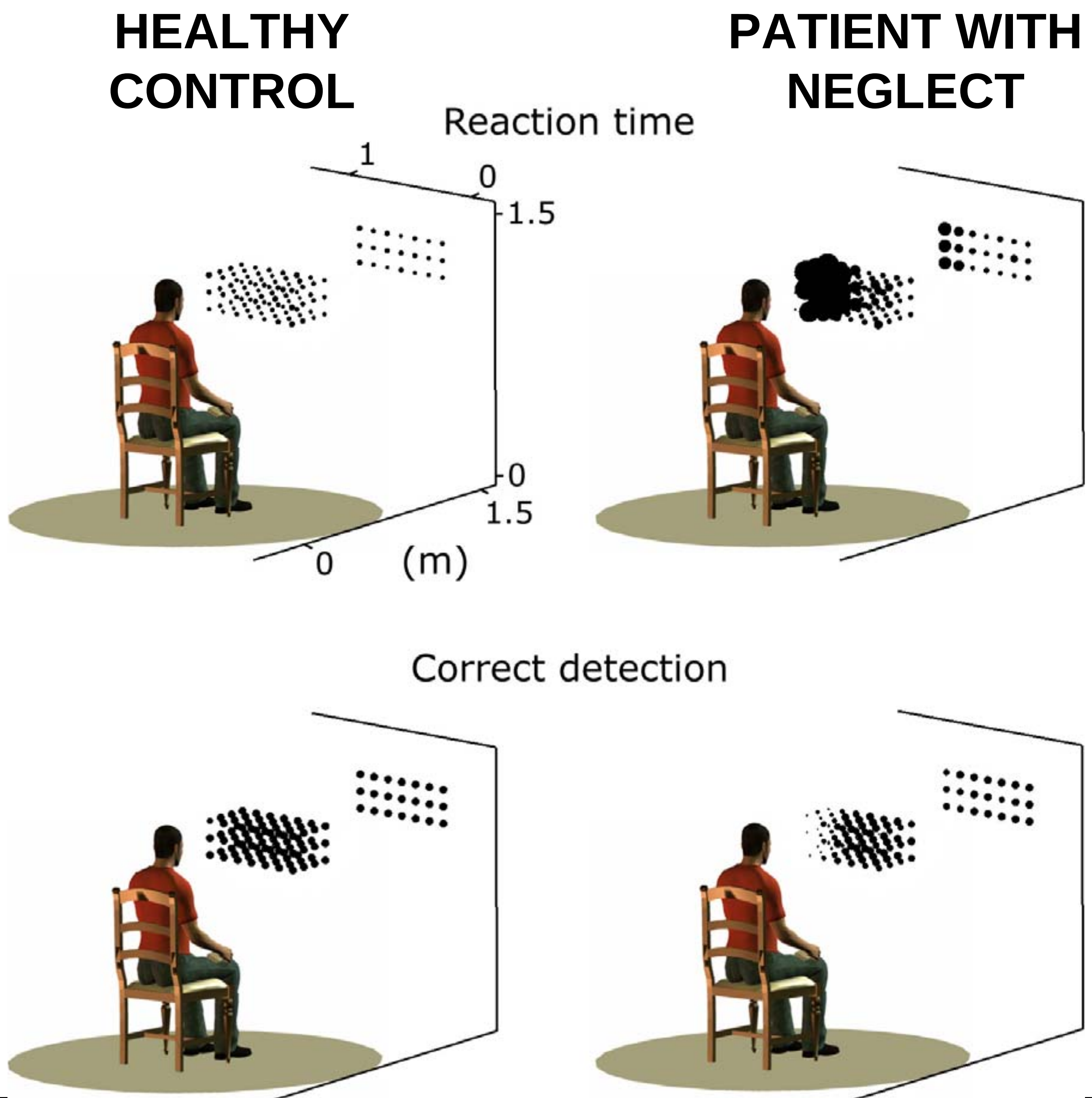



Can you use robotics and/or display feedback technology to train movement skills?



Detecting Hemispatial Neglect in stroke survivors (Assaf Dvorkin)



Interactive technology can

Novelty

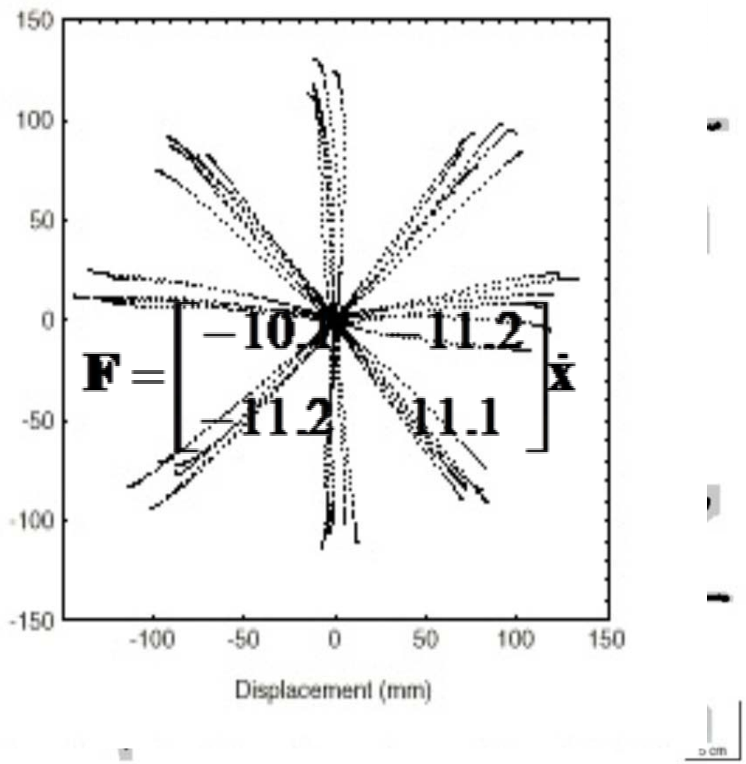
- Give Precision guidance
- Assist as needed; wean
- Track & store progress
- Rapidly present scenarios
- Render “unreal” forces
- Challenge (train robustness)
- Distort reality & cause adaptation
- Possibly be worn and/or taken home

Long latencies make feedback control impossible for most everyday movements

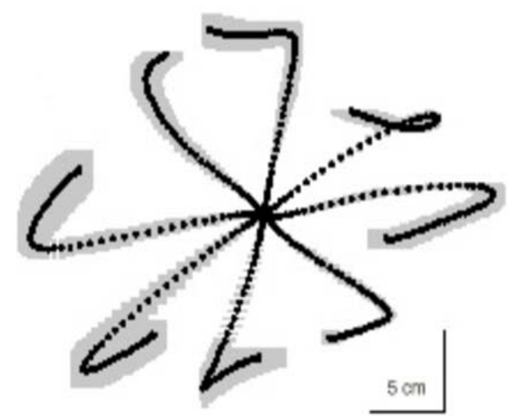
REFLEX TYPE:	Movement Latencies	Frequencies
Musculoskeletal Impedances	instantaneous	∞
Spinal	30-80 msec (Dewhurst, 1967)	1.7 Hz (Hogan, 1990)
Triggered	80-120 msec (Crago, et al., 1976)	0.6 Hz (Hogan, 1990)
Supraspinal (long)	120-180 msec (Schmidt, 1988)	0.5 Hz (Hogan, 1990)
Vision	100 msec (Nashner and Berthoz, 1978)	0.6 Hz (Hogan, 1990)
Vestibular	102 msec (Melvill Jones and Watt, 1971)	0.6 Hz (Hogan, 1990)

Background on robotic force field training
adaptation and after-effects

PROGRESSIVE TRAINING:



THEN TURN OFF THE FORCES:



"After-effects"

Shadmehr, R and Mussa-Ivaldi, FA (1994) Journal of Neuroscience 14: 3208-3224.

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Dynamic Model of the Arm & controller

Functional form assumptions

$$\underbrace{I(x)\ddot{x} + G(x)}_{D} = 0 \qquad \text{(uncontrolled)}$$

$$D - C = 0 \qquad \text{(controlled)}$$

$$\underbrace{\underbrace{\{I(x)\ddot{x} + G(x,\dot{x})\}}_{D} - \overbrace{\{\ \underbrace{\hat{I}(x_{E(t)})\ddot{x}_{E(t)} + \hat{G}(x_{E(t)},\dot{x}_{E(t)})}_{C_{FF}} + \underbrace{Z[x_{E(t)} - x]}_{C_Z}\ \}}^{C}}_{M(x,\dot{x},\ddot{x},x_{E(t)}\,|\,18 params)} = 0$$

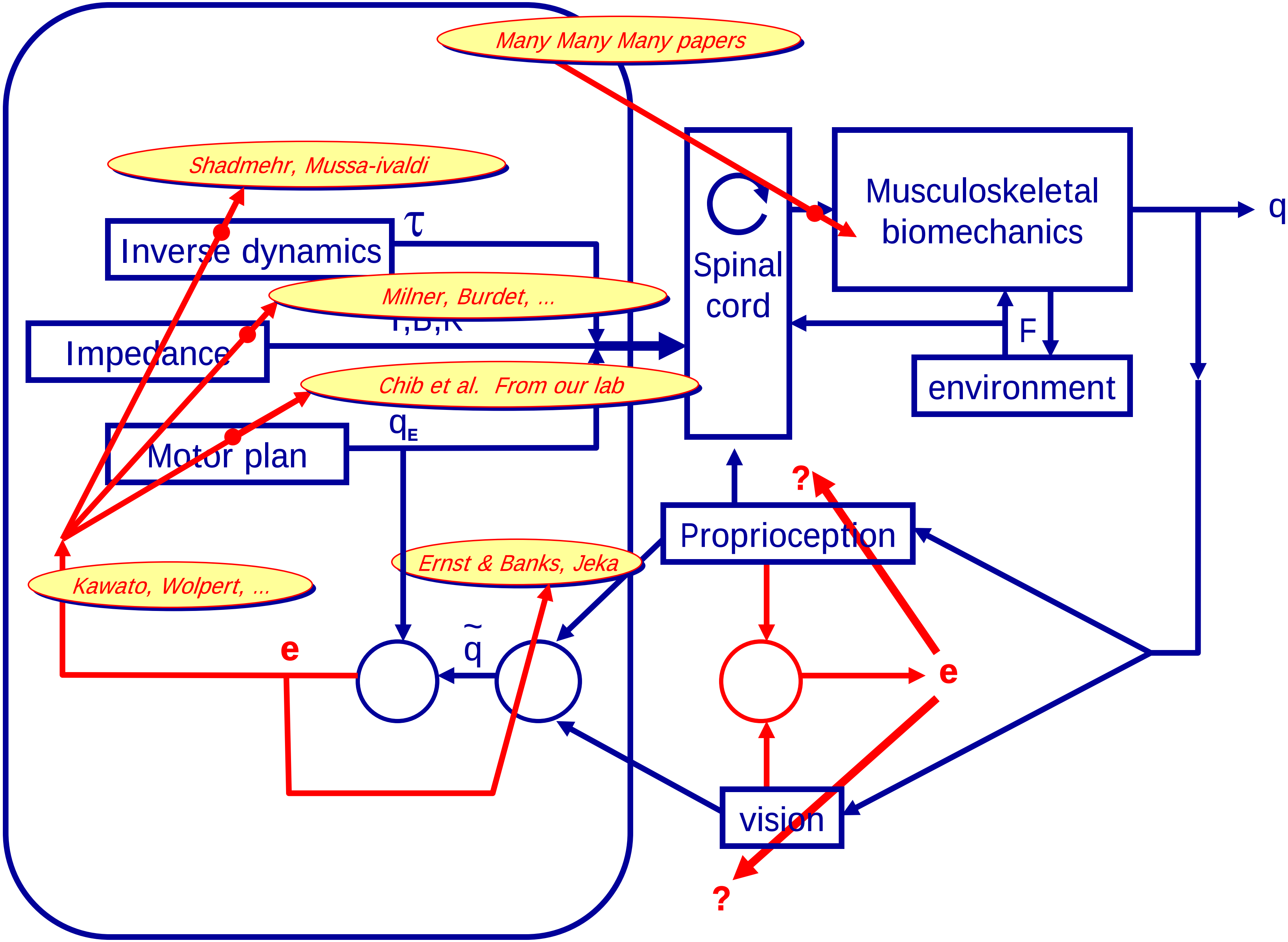
$$simplest\,learning\,rule:$$

$$\tau_i = \tau_{i-1} + \mu(e_{i-1})$$

Adaptive Training

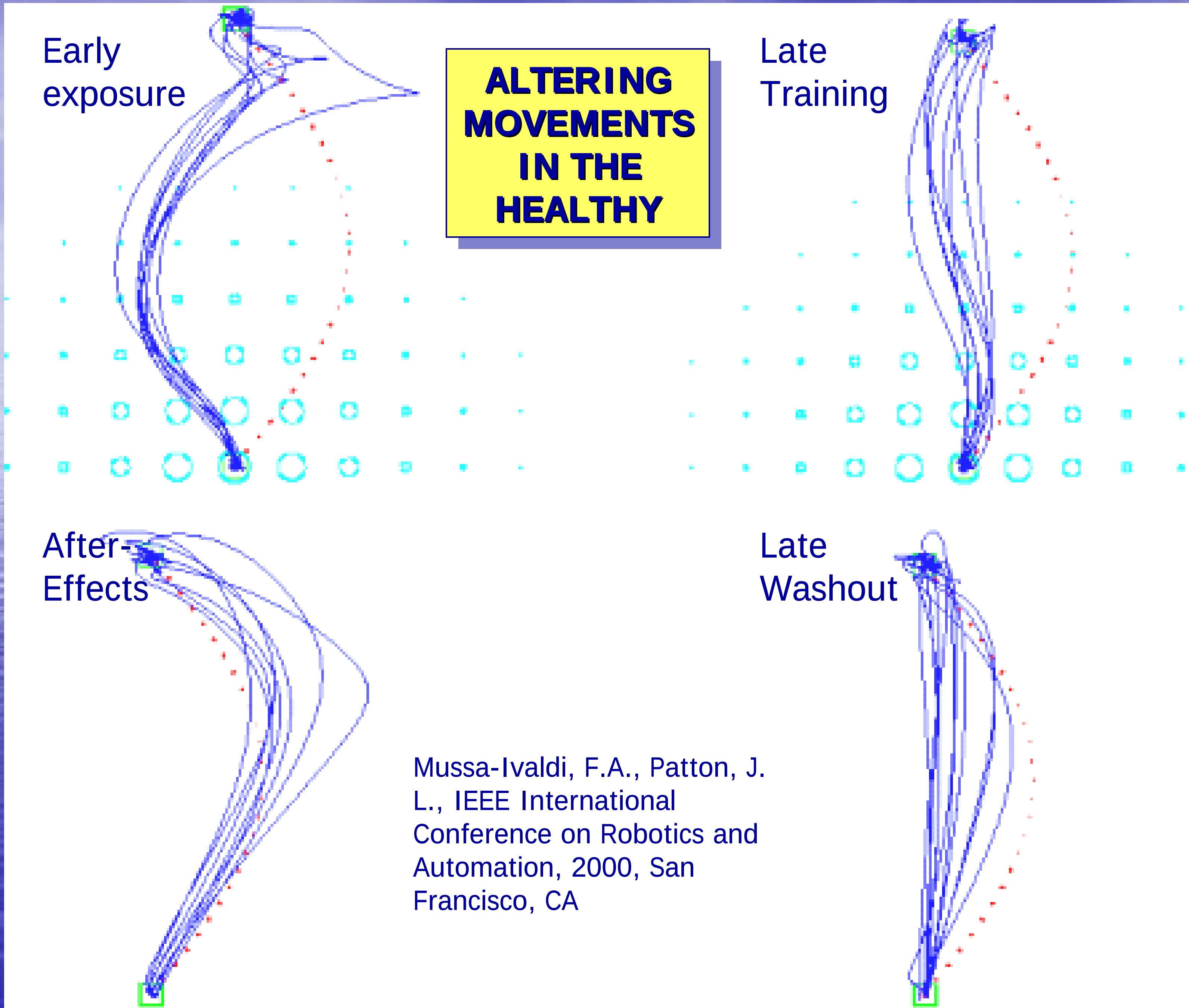
Techniques for possibly facilitating learning

- Human-human collaboration
- Custom-designed force fields
- Custom-designed Visual distortions
- Error augmentation (force and vision)
- Obstacle avoidance (changes desired traj)
- Sensory crossover-teach visual w/force
- Gradual learning
- Stochastic Resonance (injected noise)
- Intermanual and bimanual transfer
- Manipulation of stability limits

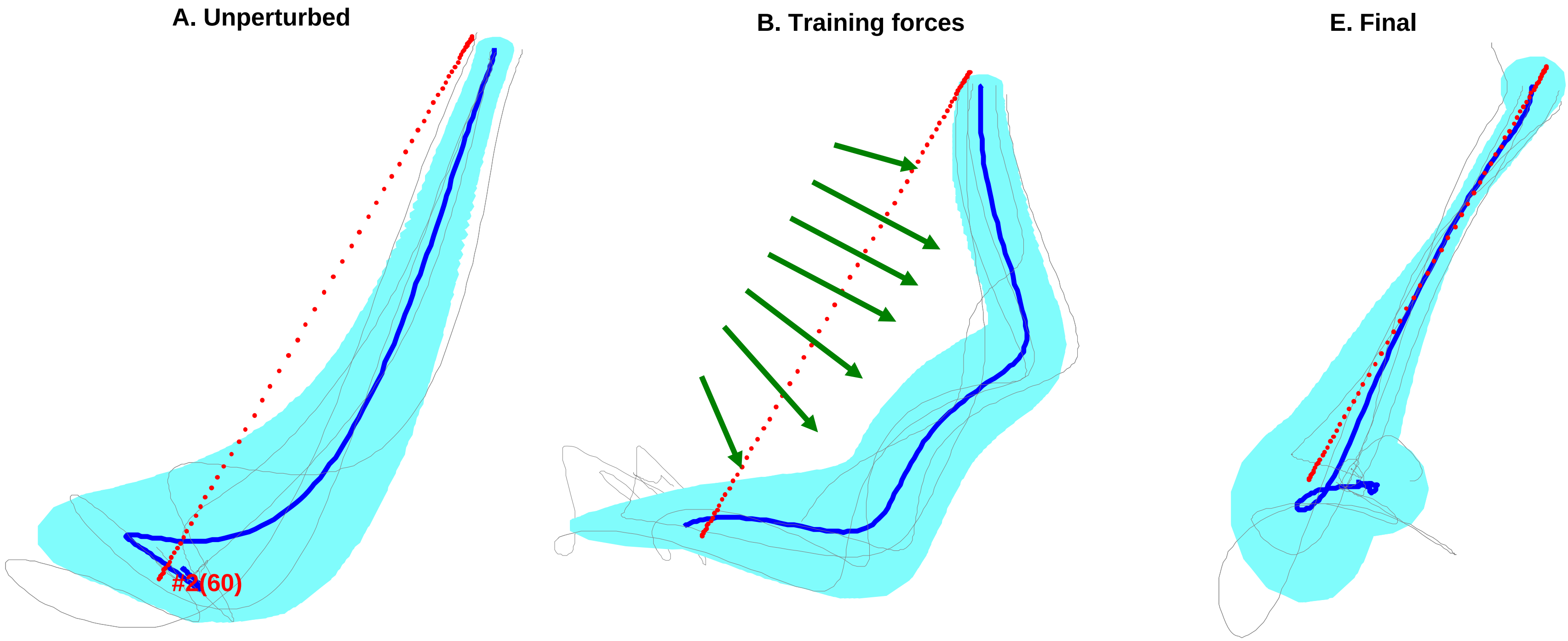


Many Many Many papers
Shadmehr, Mussa-ivaldi
Inverse dynamics
τ
Milner, Burdet, ...
I,B,K
Impedance
Chib et al. From our lab
q_E
Motor plan
Spinal cord
Musculoskeletal biomechanics
q
F
environment
?
Proprioception
Ernst & Banks, Jeka
Kawato, Wolpert, ...
e
$\tilde{q}$
e
vision
?

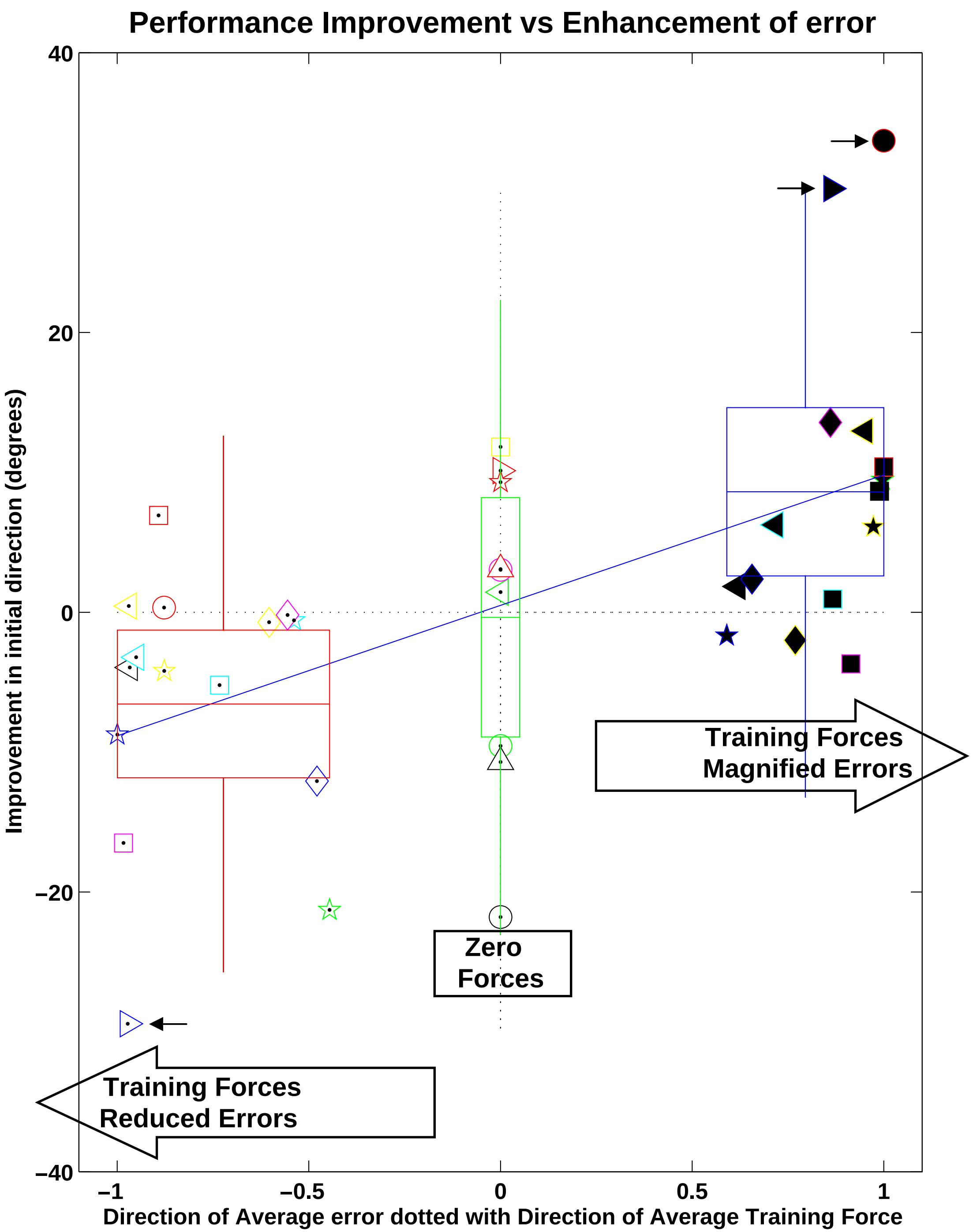
ALTERING MOVEMENTS IN THE HEALTHY



Mussa-Ivaldi, F.A., Patton, J. L., IEEE International Conference on Robotics and Automation, 2000, San Francisco, CA



Patton, J. L., M. E. Phillips-Stoykov, et al. (2006). "Evaluation of robotic training forces that either enhance or reduce error in chronic hemiparetic stroke survivors." Experimental Brain Research 168(3): 368-383.



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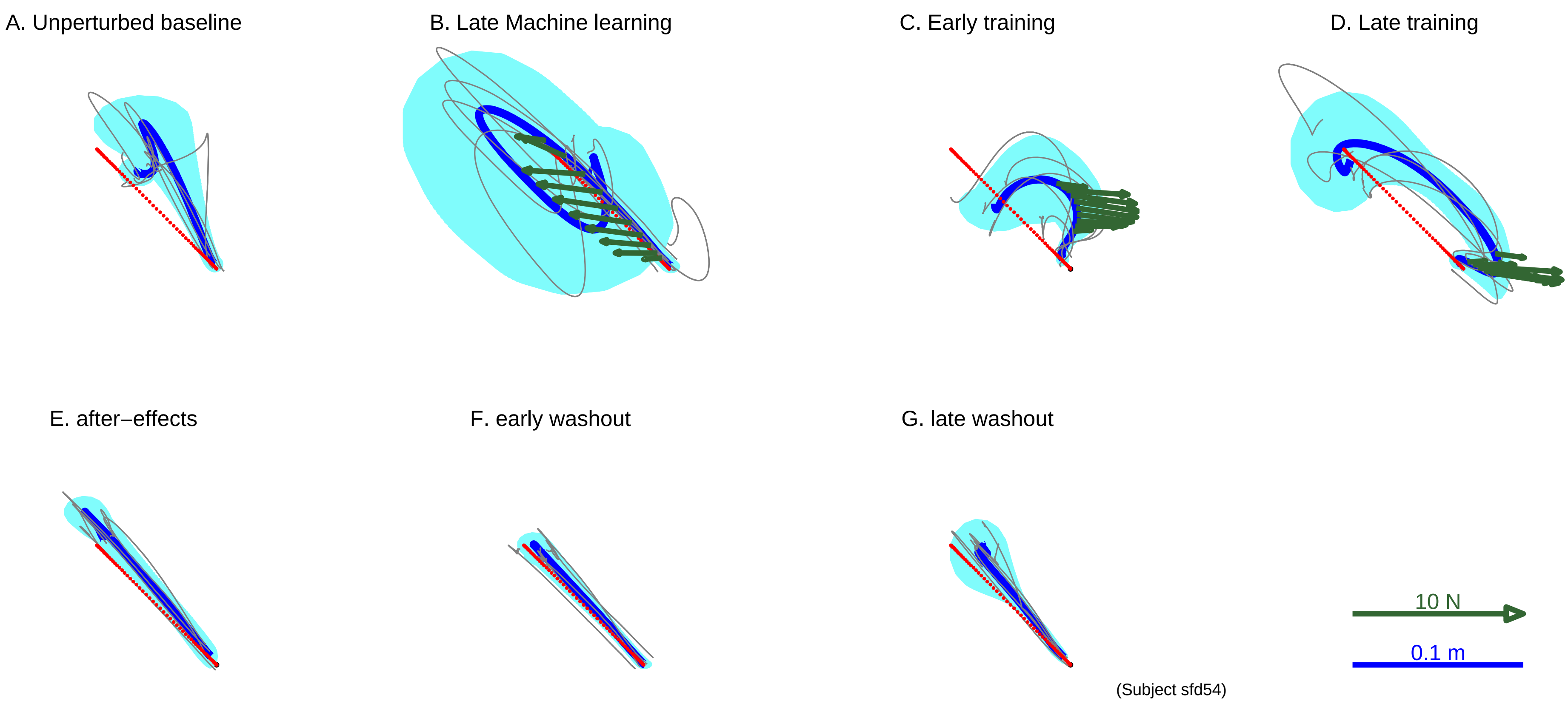
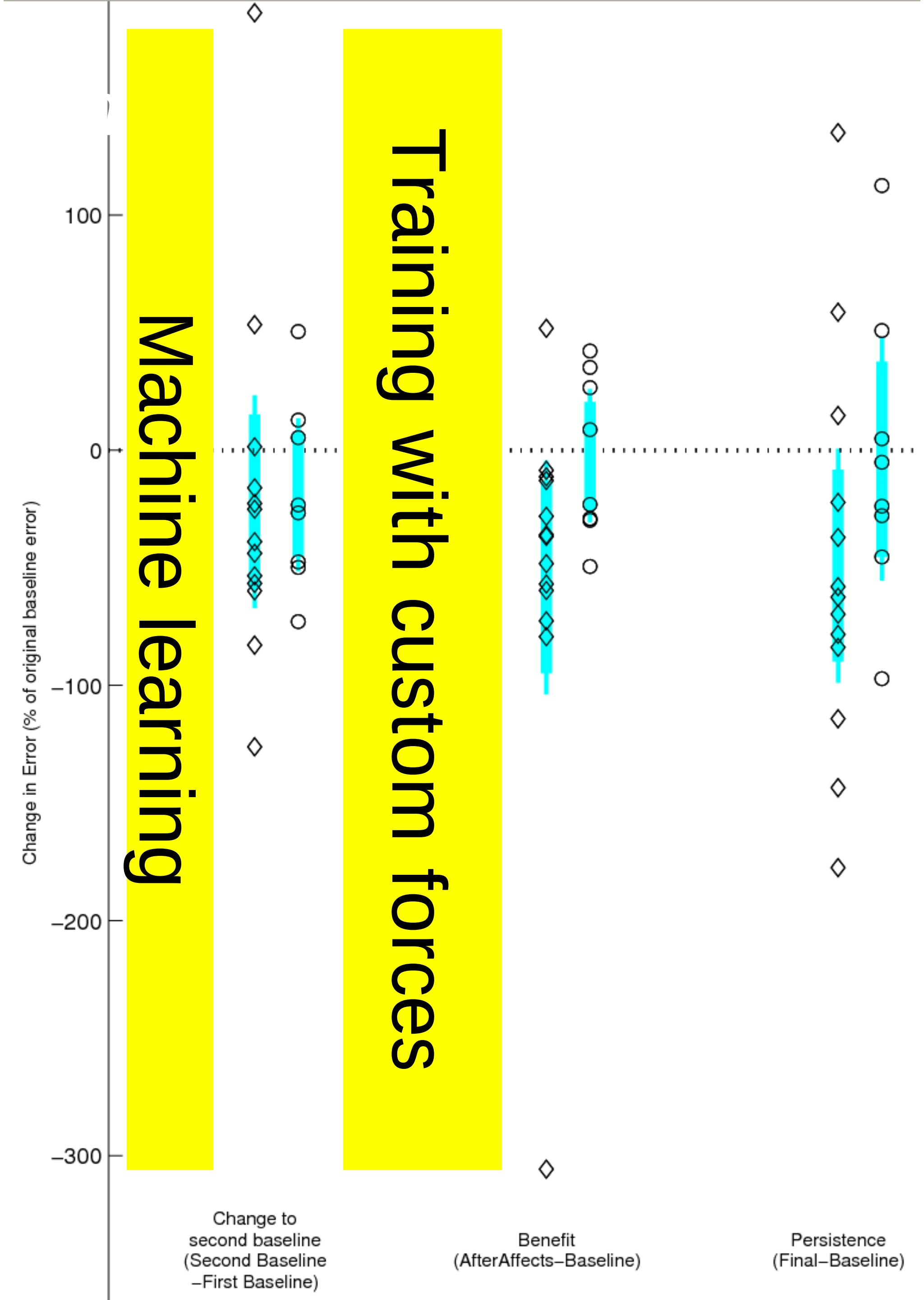


Patton Et Al (2006) Custom-designed haptic training for restoring reaching ability to individuals with stroke. *JRRD* in press

Custom-Designed Training Forces:

Error reduces significantly in stroke survivors



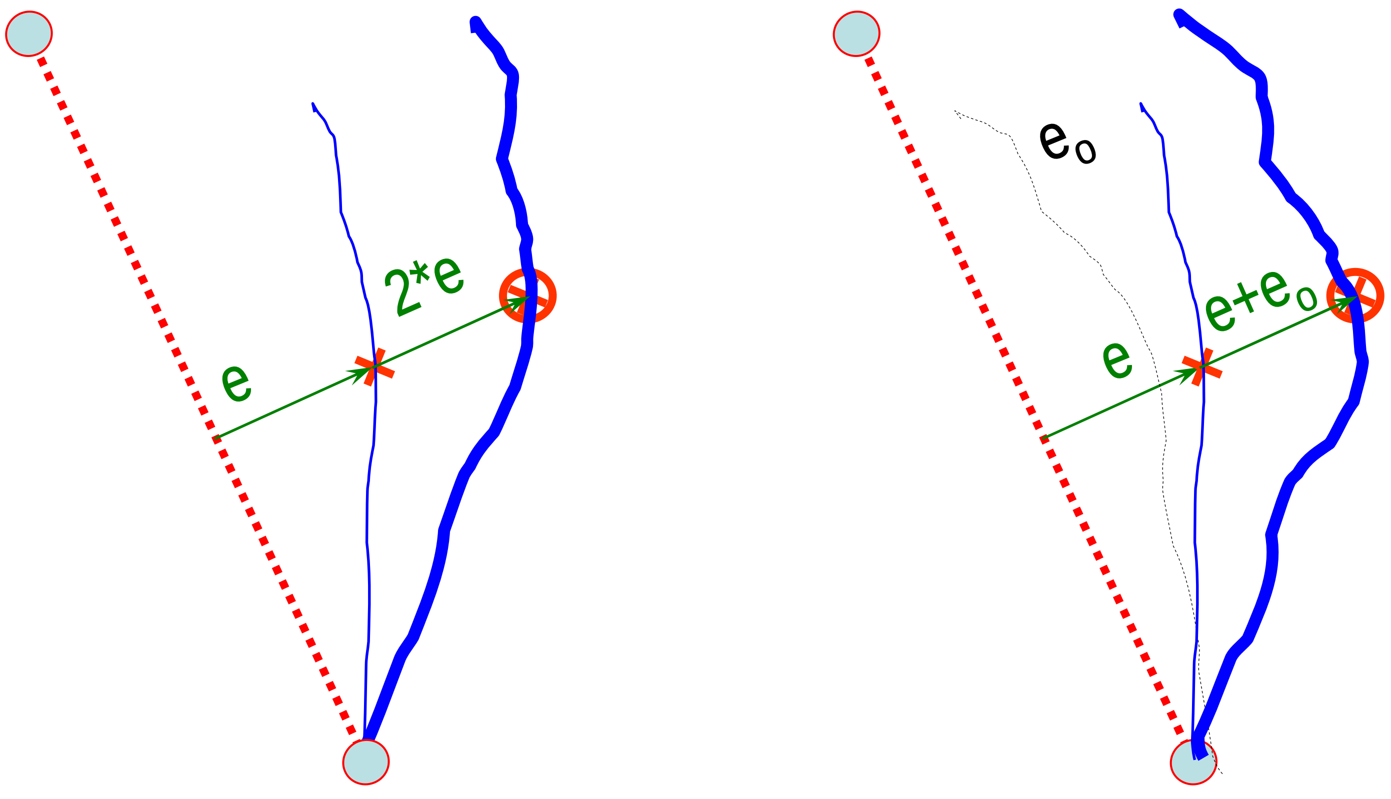
Patton Et Al (2005) Custom-designed haptic training for restoring reaching ability to individuals with stroke. *JRRD* in press

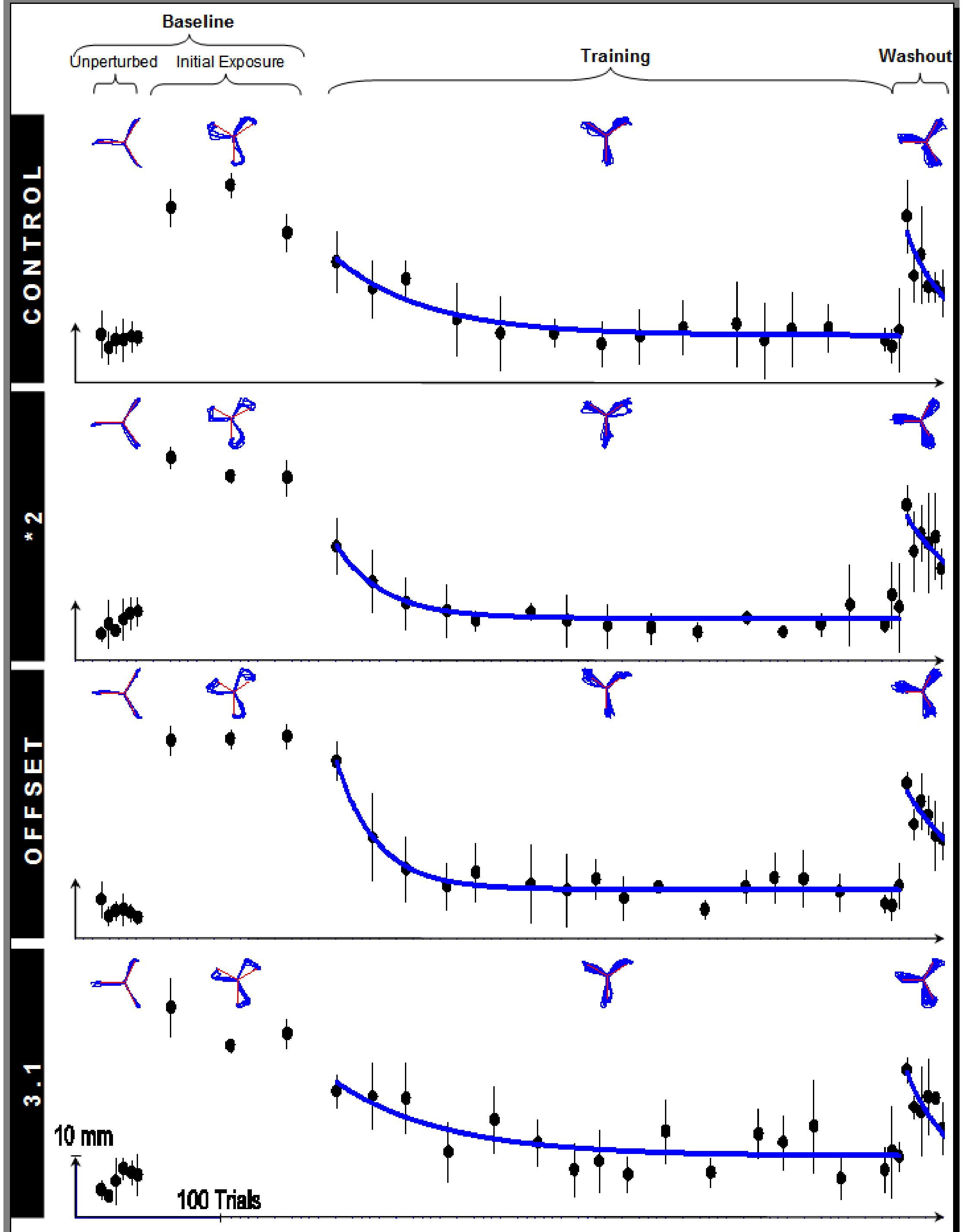
Error Augmentation

ERROR AUGMENTATION CANDIDATES

GAIN

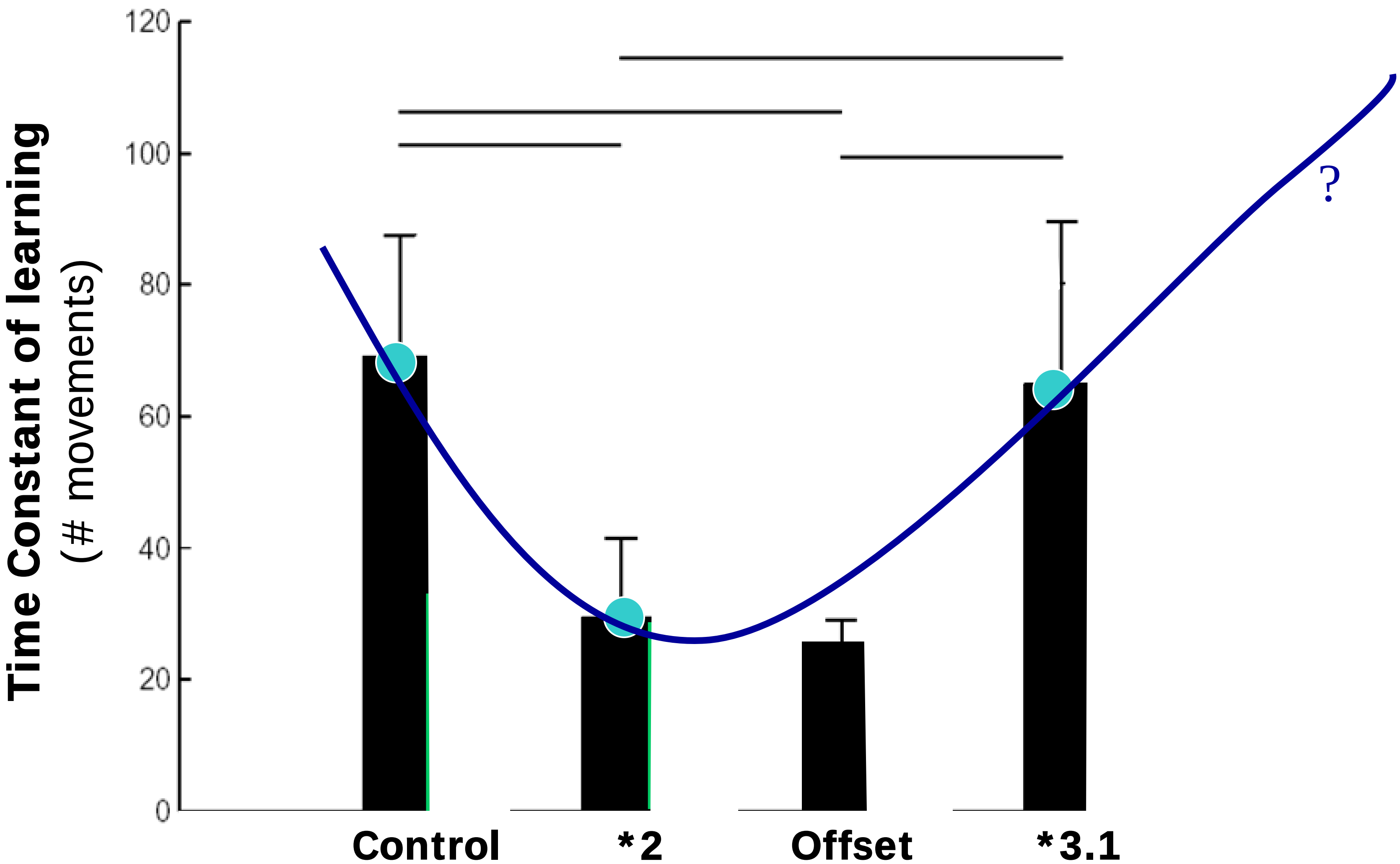
OFFSET





Baseline
Unperturbed
Initial Exposure
Training
Washout
CONTROL
* 2
OFFSET
3.1
10 mm
100 Trials

Error Augmentation speeds up & increases learning in healthy individuals



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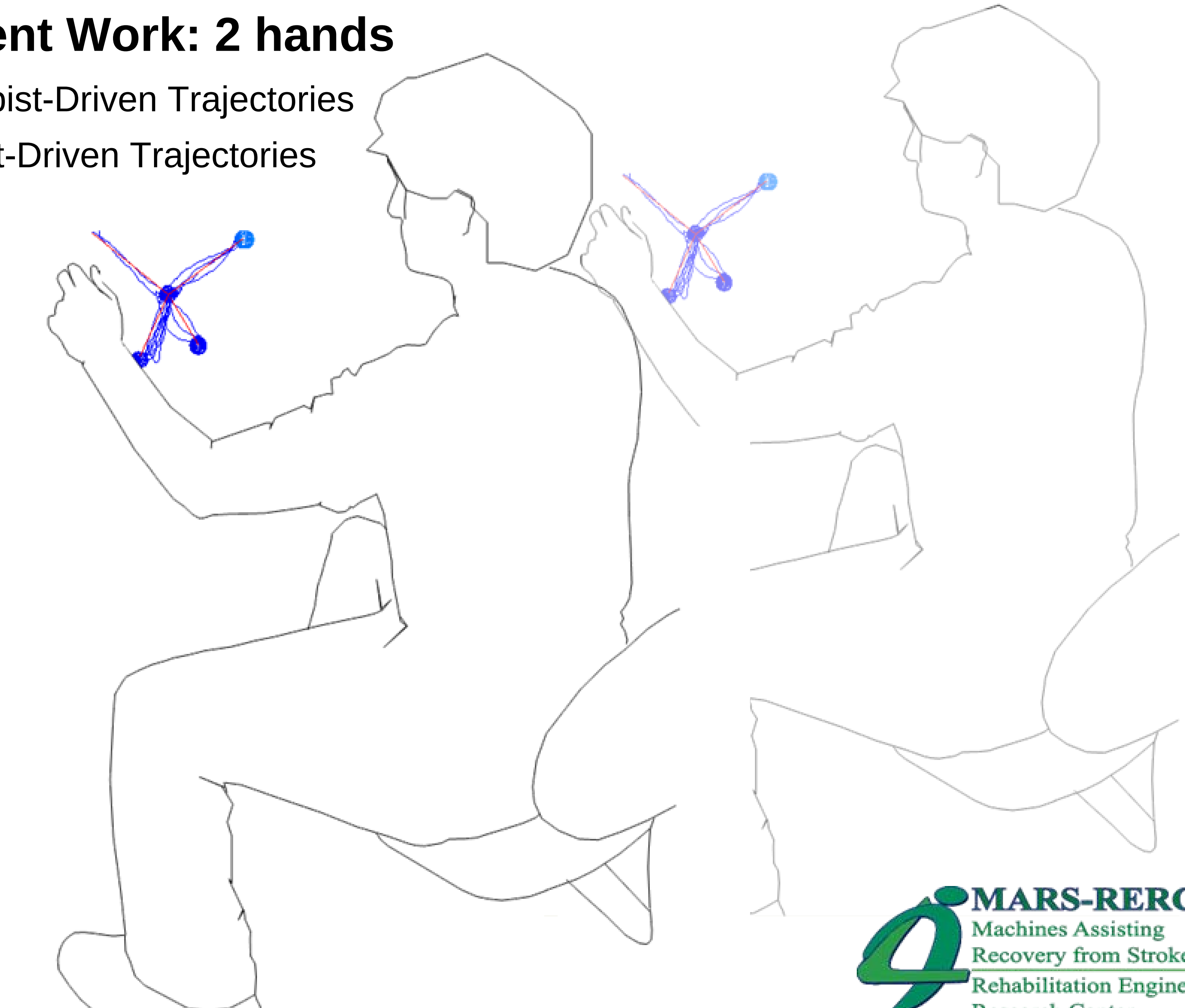
Current Work: 2 hands

•Therapist-Driven Trajectories

•Patient-Driven Trajectories



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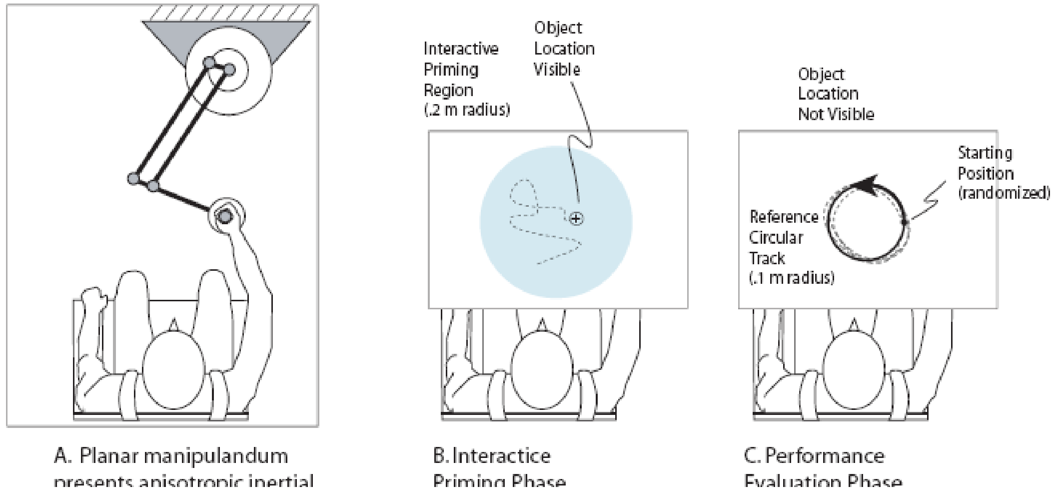
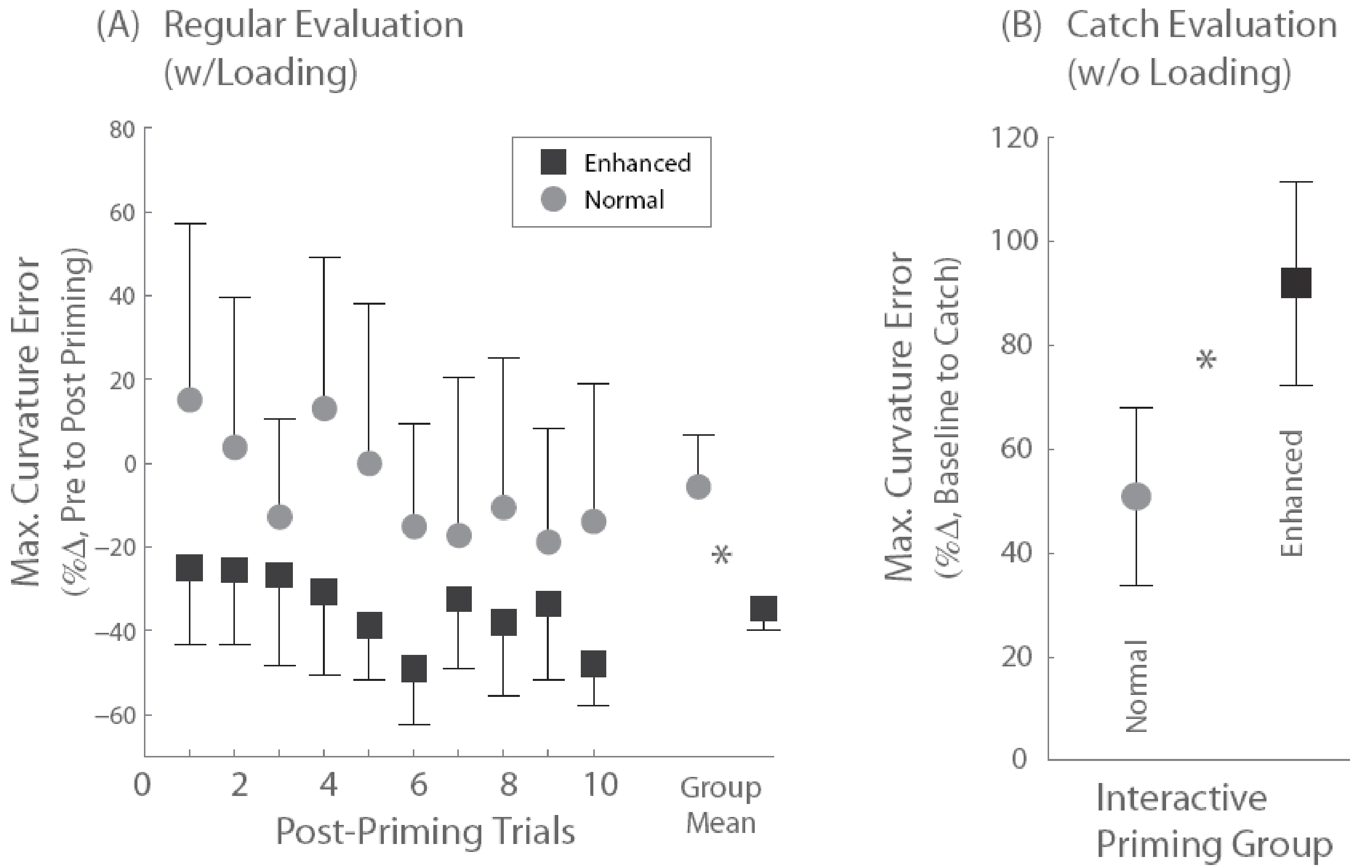
Free exploration learning with error augmentation via negative damping enhances learning

(Felix Huang)





Applications for adaptive training

- Rehabilitation
- Teleoperation
- Human-machine interactions
- Learning and Co-Learning a Neural Machine interfaces

Thanks

- W. Z. Rymer
- F. A. Mussa-Ivaldi
- F. Huang
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- M. Kovic
- R. Haner
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- P. Shah
- C. Raasch
- L. Kahn
- D. Sha

- NIH R01 R01 NS053606
- NIDRR H133A080045
- NIDRR H133E0700 13
- AHA 0330411Z
- NIH R24 HD39627
- NIH 5 T32 HD07418
- NIH 5 RO1 NS 35673
- NIH F32HD08658
- NIDRR RERC 0330411Z
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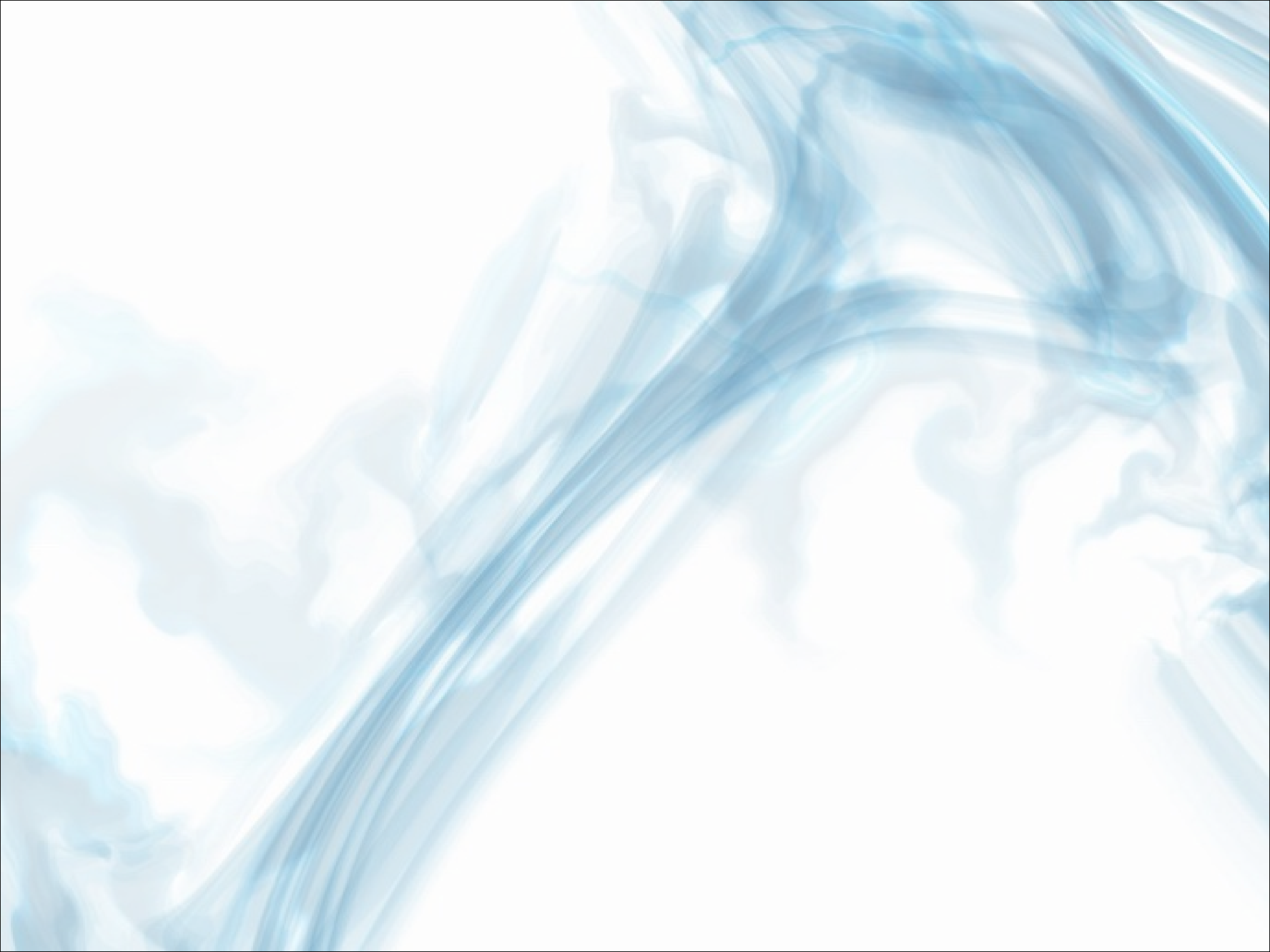
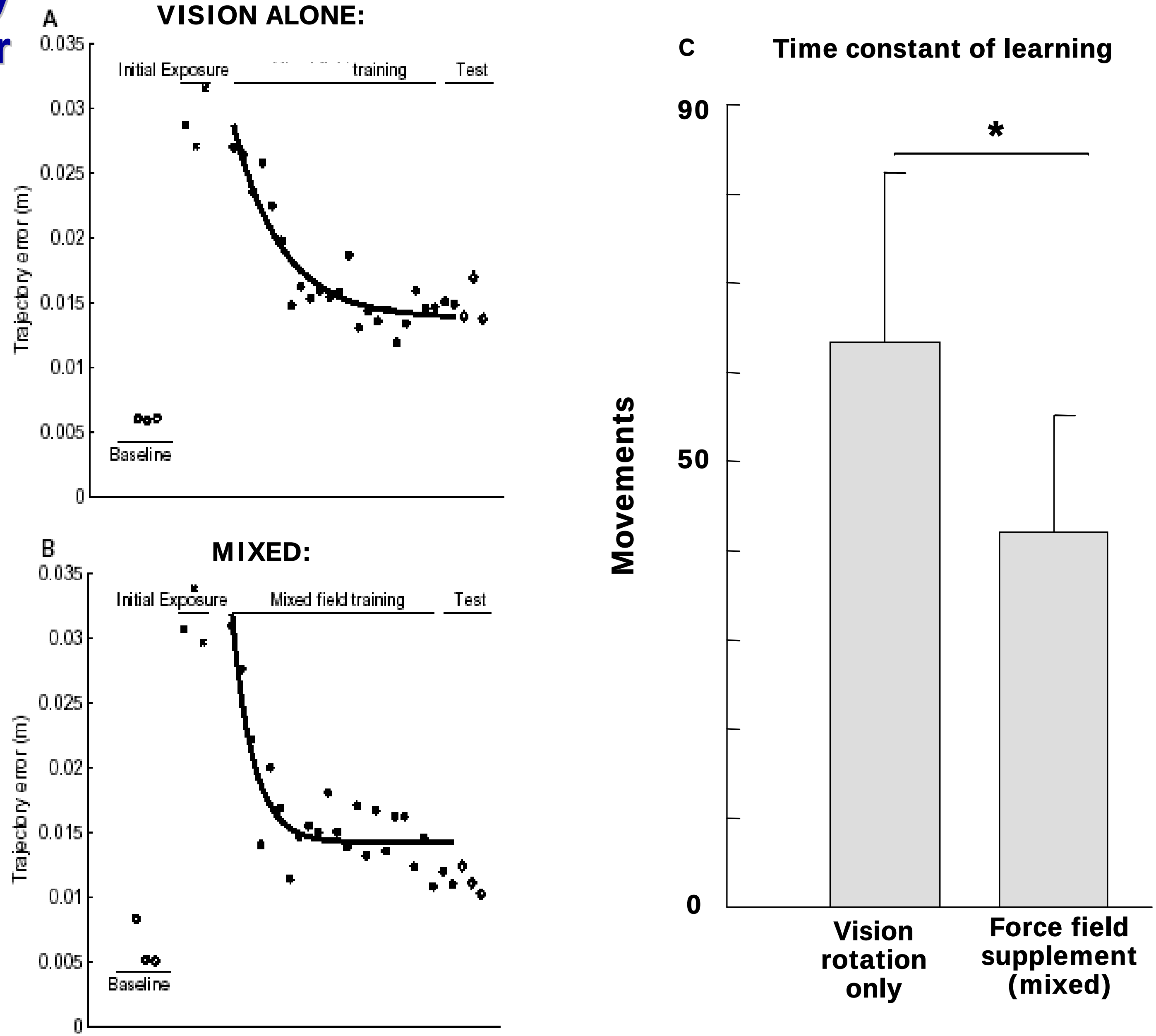


Sensory Crossover



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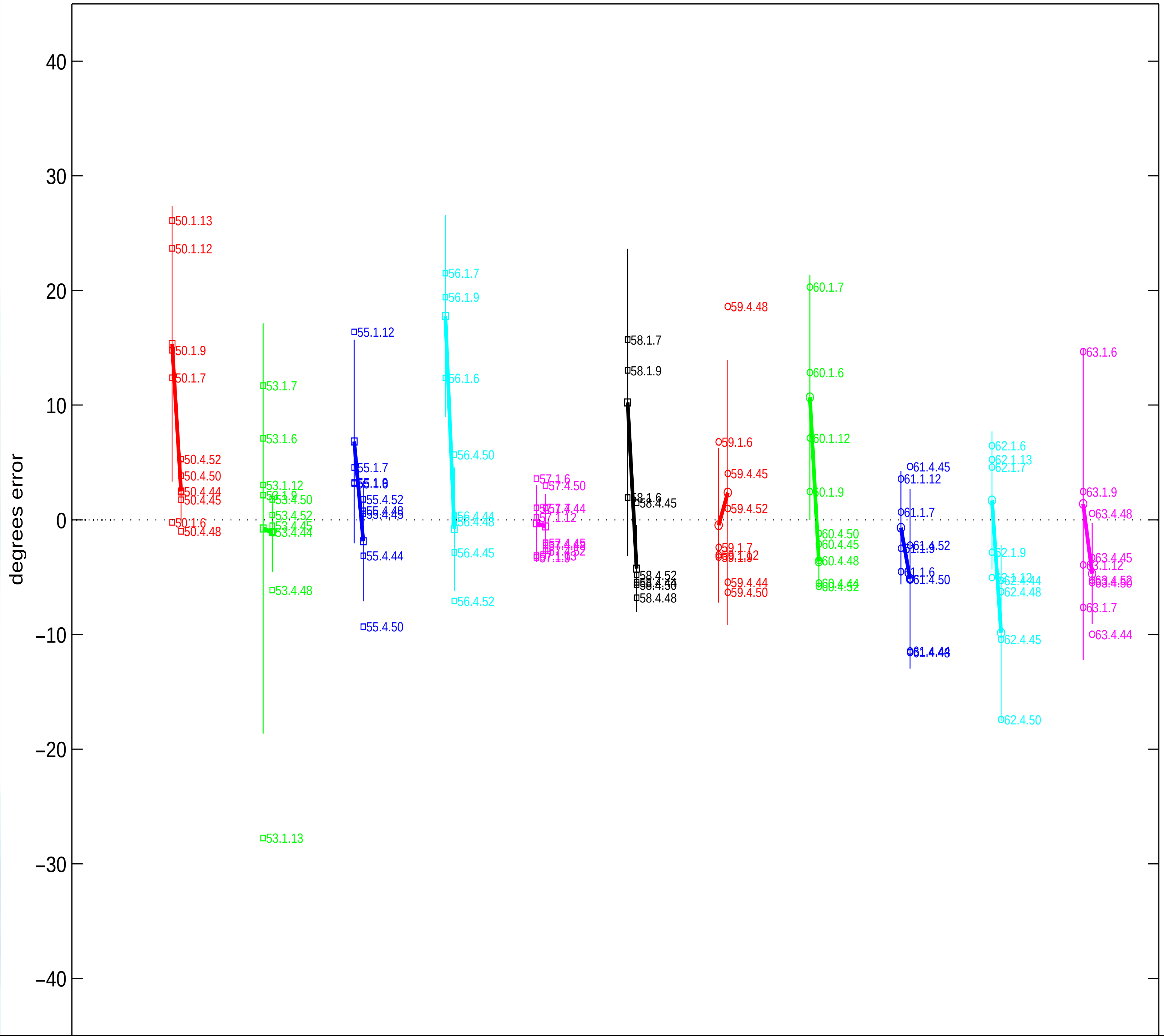
Initial direction error with desired for movement direction of 315degrees



Assessments

- Blinded Rater
- Assessments pre and post each tx.
  - “Reach and retrieve” (rag on a stick)
  - Functional workspace when reaching towards 9 targets on periphery
  - Wolf Motor Function Test
  - Box and Blocks
  - Fugl-Meyer

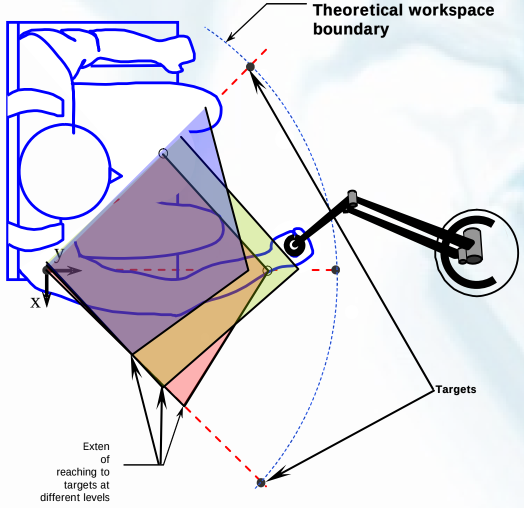


Figure 3: Schematic example of the directions and layers of the functional workspace determined in the workspace parts of the experiment.

Secondary assessments:

- How much time (tx vs. setup)?
- how long did it take to achieve therapeutically meaningful effect?
- Which treatment engaged / frustrated patient
- Therapist opinion

EA haptic forces

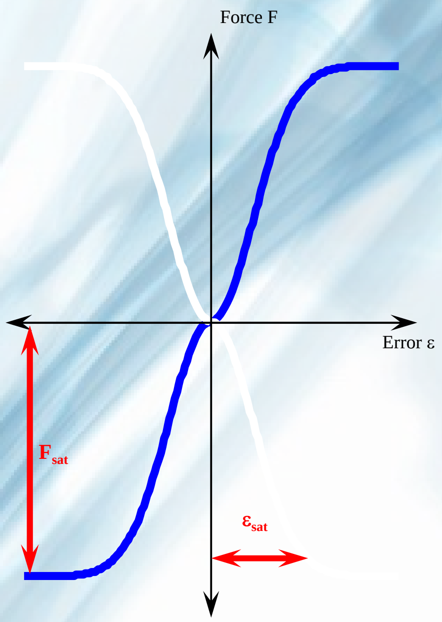


Figure 11: The double exponential function governing the error-augmentation (dashed line defined in Equation 1.

Inclusion Criteria

- Chronic Stroke (8+ mos post) *(Changed to 6+ mos in NW IRB)*
- Available medical records/radiographic info
- Ischemic infarct in MCA *(not included in NW IRB)*
- Primary Motor Cortex Involvement *(not included in NW IRB)*
- Some degree of shoulder and elbow mvmt.
- AMFM 40-50 *(Changed to 25-50 in NW IRB)*

Exclusion Criteria

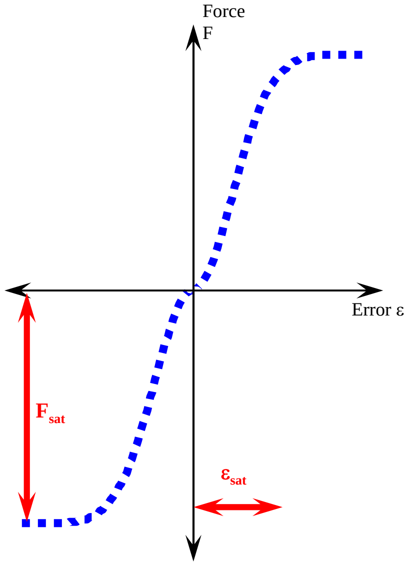
- Bilateral paresis
- Severe sensory deficits
- Severe spasticity (MAS = 4)
- Severe contracture *(added to NW IRB)*
- Aphasia, cognitive impairment or affective dysfunction that would influence the ability to perform experiment
- Severe concurrent medical problems
- Diffuse/multiple lesion sites or multiple stroke events
- Hemispatial neglect/inattention or field cut that would influence the ability to perform experiment
- Ataxia *(added in NW IRB)*
- Significant pain (greater than 5/10) in UE *(added in NW IRB)*
- Botox injection in previous 3 months *(added in NW IRB)*
- Participation in other UE research projects *(added in NW IRB)*

Statistics

- Randomized Mixed effects model
  - Trend affecting the hypothesis on treatment type?
  - Period-by treatment interaction
  - Carry over effect
  - Patient-by-treatment interaction
- Bayesian?
  - Early results
  - Alternative to testing

R1: AIM 1, Experiment 1.1

- Therapist-Driven Trajectories
- 17 subjects, random order of groups
- 4 weeks of tx, 1 treatment per week
- (45 min)
- 4 groups
  - EA with visual distortion
  - EA with haptic forces
  - EA with visual distortion and haptics
  - No EA



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